Botanical Insecticides in Plant Protection

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Summary

Botanical insecticides are natural compounds with insecticidal properties and their use in crop protection is as old as agricultural practice. Although they have been in use for over one hundred years, the advent of synthetic insecticides has unfortunately displaced their use today. Due to fast action, low cost, easy application and efficiency against a wide range of harmful species, synthetic insecticides have become an important part of pest management in modern agricultural systems. However, after decades of use, their negative side effects, such as toxicity to humans and animals, environmental contamination, and toxicity to non-target insects have become apparent and interest in less hazardous alternatives of pest control is therefore being renewed. Plant species with known insecticidal actions are being promoted and research is being conducted to find new sources of botanical insecticides. The most important botanical insecticide is pyrethrin, a secondary metabolite of Dalmatian pyrethrum, neem, followed by insecticides based on the essential oils, rotenone, quassia, ryania and sabadilla. They have various chemical properties and modes of action. However, some general characteristics include fast degradation in sunlight, air and moisture, and selectivity to non-target insects. Unfortunately, neither of these insecticides is widely used as a pest control agent but is recognized by organic crop producers in industrialized countries.

Key words

azadirachtin; botanical insecticides; essential oils; neem; pyrethrin; rotenone

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Introduction

Plant pest protection is an important issue for the agricultural community. Before the development of synthetic insecticides, materials derived from plants provided means for crop protection. Plant species have the ability to synthesize a variety of secondary metabolites that are not essential for their growth and development (Rosenthal and Berenbaum, 1991), but are important in the protection against predators and microbial pathogens and interaction of plants with other organisms (Schafer and Wink, 2009). Many secondary metabolites have insecticidal, repellent as well as antifeedant activity. Furthermore, they cause reproduction retardation and act as insect growth regulators (IGR) (Rice and Coats, 1994; Isman, 2000).

The use of plant secondary metabolites for the protection of crops from insect species likely originated at the same time as crop protection itself, thousands of years ago (Thacker, 2002). Crude plant extracts, plant materials or whole plants have been used for several centuries and were known in tribal or traditional cultures around the world (Weinzierl, 2000). The first known written references concerning plant insecticides and their application against pests date back to approximately 400 B.C. from Ancient Rome (Dayan et al., 2009). Botanical insecticides with long history of traditional use include pyrethrum, neem, rotenone and sabadilla (Weinzierl, 2000). They have been used to protect stored commodities or to repel various pests from human habitations (Isman & Machial, 2006). Powdered flowers of the Dalmatian pyrethrum (*Tanacetum cinerariifolium* /Trevir./ Sch. Bip) have been traditionally used in Croatian agriculture and households. Neem has been traditionally used in India, rotenone in East Asia and South America and sabadilla in Central and South America. In the nineteenth and early twentieth centuries, through advances in chemistry, better defined plant extracts, such as derris, nicotine or quassia came into use. Rotenone isolated from *Derris eliptica* (Wall.) Benth was introduced in 1850 as a plant insecticide (Weinzierl, 2000). It was also used as a commercial pesticide, reflecting its original use over 300 years ago. From 1690, water extracts of tobacco were used in England to kill garden insects and by the 1890s, the principal active compound, nicotine, was identified (Weinzierl, 2000). Nicotine and other nicotine compounds were used as contact insecticides and fumigants to control aphids, thrips and mites. The earliest insecticidal applications of quassia date from 1880 when it was successfully used against aphids (Pluke et al., 1999).

The development of synthetic insecticides began in the 1940's resulting in the abandonment of botanical insecticides in commercial agriculture. The commercial success of synthetic insecticides was due to high efficiency, fast action, ease of use and low cost. Twenty years later, numerous negative side effects of synthetic insecticides in modern agricultural systems have been noticed, including the development of insect resistance, pesticide food contamination, environmental pollution problems, the disruption of natural balance, toxicity to non-target organisms, and the most important, negative impact on human health. Negative side effects of synthetic insecticides have led to the investigation of various alternative measures to conventional pest management practices and the development and use of natural plant protection agents.

Botanical insecticides have certain advantages; they do not persist in the environment, they present a relatively low risk to non-target organisms (beneficial predators and parasites) and they are relatively nontoxic to mammals (Weinzierl, 2000; Scott et al., 2003). They usually break down rapidly in the environment and are easily metabolized by animals receiving sub-lethal doses (Ling, 2003). Today, nearly 200 plants with insecticidal properties are known, but unfortunately only a few of them have been properly evaluated (Pavela, 2009). Moreover, botanical insecticides are not widely used in conventional crop production but they are recognized by organic crop producers in industrialized countries. Reasons for limited commercial development of botanical insecticides are their relatively slow action, variable efficiency, lack of persistence and inconsistent availability (Isman, 2008) when compared to synthetic insecticides. Other barriers to commercialization of botanical insecticides are scarcity of the natural resource, standardization, quality control and registration (Isman, 1997). Among botanical insecticides, pyrethrin and neem are the most exploited commercially and the use of rotenone is decreasing, while ryania and sabadila are in limited use. Furthermore, insecticides based on plant essential oils are entering the pesticide market (Isman, 2006). This paper provides a brief history of botanical insecticides and reviews their chemical properties, toxicology, effectiveness and use.

Pyrethrum

Pyrethrin is the secondary metabolite of Dalmatian pyrethrum (*Tanacetum cinerariifolium* /Trev./ Schultz Bip.), a perennial plant species (Asteraceae) endemic to the East coast of the Adriatic Sea (Grdiša et al., 2009). It is a mixture of six active compounds (pyrethrin I and II, cinerin I and II and jasmolin I and II), whereas pyrethrin I, cinerin I and jasmolin I are the esters of chrysanthemic acid, and pyrethrin II, cinerin II and jasmolin II are the esters of pyrethric acid (Head, 1973). Typical pyrethrin extract contains pyrethrins, cinerins and jasmolins in the proportions 10:3:1 (Crombie, 1995), with the ratio of pyrethrin I to pyrethrin II being approximately 1.0, although it can vary between 0.5 and 3.5 in some breeding lines (Bhat, 1995). In the study of Grdiša et al. (2013), the total pyrethrin content of natural Dalmatian pyrethrum populations ranged from 0.36 to 1.30% (dry flower weight; DW), while the pyrethrin I/pyrethrin II ratio ranged from 0.64 to 3.33%. Flower heads contain the majority of pyrethrins, while in the other plant parts they are found in minor quantities (Kolak et al., 1999). In different flower parts the concentration of pyrethrin varies and approximately 94% of pyrethrin is accumulated in the secretory tissue of the achenes (Kiriamiti et al., 2003; Morris et al., 2005), hence they are protected from photo degradation (Casida, 1980). Minor quantities are found in disc florets (2.0%), ray florets (2.6%) and receptacles (2.6%) (Head, 1966). Piretrin I and piretrin II are predominant and the most active components (Head, 1966; Casida and Quistad, 1995; Crombie, 1995), while cinerin I, cinerin II and jasmolin I and II are present in lower concentrations and characterized with noticeable lower bioactivity (Zong-Mao and Yun-Hao, 1996). Pyrethrin I acts in minutes, and alone is toxic, while pyrethrin II has a high knock-down effect appearing a few hours after its application. Insects easily metabolize pyrethrin II and recover in a few hours (Sawicki and Thain, 1962), however their combination has an outstanding, wide range effect on insect species (Winney, 1979). They are contact poisons that rapidly penetrate into the nervous system. According to Tomlin (2000), they bind to sodium channels of nerve cells, prolonging their opening and thereby causing the death of the insect. Sonderlund (1995) also proved that pyrethrins affect the nervous system of insects; they block nerve junctions and the action of voltage-sensitive sodium channels, causing a knock-down effect, paralysis and death (Davies et al., 2007). Pyrethrins are quickly degraded when exposed to light, air, water and high temperatures (Allan and Miller, 1990) and therefore do not accumulate in food chains and ground water (Cochran, 1995; Jovetić and de Gooijer, 1995) and do not persist in the environment beyond a few weeks (Todd et al., 2003). Antonious (2004) determined the half-life of pyrethrin I and II in field conditions to be less than two hours. Crosby (1995) determined that under dark conditions, there is little degradation of pyrethrin over time, whereas in the light, rapid degradation from 100% to less than 1% of pyrethrin within five hours has been observed. The pyrethrins are slowly broken down in water and are therefore toxic for some fish and aquatic invertebrates. However, in the presence of microbial communities, the degradation is expected to be faster through oxidative metabolism (Gunasekara, 2004). Due to their high biodegradability they are safe and environmentally friendly and present an ideal substitute for a synthetic insecticide alternative, but due to their instability, their usage is limited. As an insecticide, pyrethrin was registered in 1950 for use in agriculture, households, public health and on domestic and farm animals. It was then labeled as nontoxic to humans and animals. Such classification is no longer allowed, but it remains as one of the safest insecticides. After more than a century of their use, only a few cases of human illness, mostly allergic reactions and dermatitis, are associated with exposure to pyrethrins, caused by impurities that are no longer present in the extracts (Casida, 1980). Oral application of pyrethrins in treating human illnesses has also been reported. Their effective use in controlling intestinal worms, in doses 10-20 mg per adult and 5-10 mg per child was documented in France from 1930 to 1950 (Glynne-Jones, 2001). In their pure state, pyrethrins are moderately toxic to humans (LD_{50} 350-500 mg/kg) but technical grade pyrethrum is noticeably less toxic (LD_{50} 1500 mg/kg) (Casida and Quistad, 1995). Pyrethrins are widely used in agriculture, horticulture, store products (Silcox and Roth, 1995), households (Kennedy and Hamilton, 1995), in public health facilities (Greenhill, 2007) and for the control of animal pests (Gerberg, 1995). Pyrethrins are used as an agricultural pre-harvest treatment on forage crops, fruits, vegetables, ornamental plants, and applied as dust, emulsified substance or spray. They are often used with synergists (*e.g.*, pyperonyl butoxide), substances which suppress detoxification within the insect, thereby increasing the effectiveness of the insecticide. They are effective on a wide range of insect species including mosquitoes, sawfly larvae, caterpillars, leafhoppers, aphids and beetles (Todd et al., 2003) as well as *Culicoides variipennis* (Coquillett) (Woodward et al., 1985), house flies (Diptera) (Sheppard and Swedlund, 1999), Rosy apple aphid (*Dysaphis plantaginea* Passerini) (Wyss and Daniel, 2004), Flour beetle (*Tribolium confusum* Jacquelin du Val) (Arthur and Campbell, 2008) and many other insect species.

Neem

Neem insecticides are derived from the tropical and subtropical tree *Azadirachta indica* A. Juss. (syn. *Melia azadirachta* L.), systematically classified in the family Meliaceae. It is commonly known as neem or Indian lilac (Siddiqui et al., 2004). The neem plant is native to Southern and Southeastern Asia and today it is grown in tropical and subtropical areas of Africa, North and South America and Australia (Schmutterer, 1990). The principal active ingredient in neem is azadirachtin, a tetranortriterpenoid limonoid (Mordue and Blackwell, 1993). Azadirachtin is present in minor quantities in all parts of the tree but the highest concentration (0.2-0.6%) is found in the seeds (Govindchari, 1992). The other limonoids, such as meliantriol, salannin, nimbin and nimbidin have been found in traces (Akhtar, 2000) and contribute to overall bioactivity (Isman, 2006; Morgan, 2009; Salehzadeh et al., 2002). Azadirachtin has a wide spectrum of actions on insects such as repellent, antifeedant, insect growth regulatory (IGR), anti-ovipositional, fecundity, and fitness reducing properties (Schmutterer, 1990). The IGR effects, manifested in growth and moulting abnormalities, result from: (1) the disruption of the endocrine system by blocking the release of neurosecretory peptides that regulate synthesis and the release of ecydysteroides and juvenile hormone, and (2) the direct effects of azadirachtin on dividing cells (Mordue et al., 1993). It is effective against more than 500 insect species (Schmutterer and Singh, 1995) and primarily the Lepidoptera, Diptera, Coleoptera, Homoptera and Hemiptera orders (Sadre et al., 1983). This active compound causes mortality and has an antifeedant effect on the Colorado potato beetle (*Leptinotarsa decemlineata* Say) (Zehnder and Warthen, 1988). In addition, it was found that azadirachtin has antifungal, antibacterial and antiprotozoan activities (Mordue and Blackwell, 1993). They are safe for adults and for the eggs of many predators such as Coccinellids (Schmutterer, 1997) and they have a minimal effect on some other beneficial insect pollinators (Lowery and Isman, 1995; Naumann et al., 1994). Furthermore, azadirachtin has a low acute toxicity to mammals (Salehzadeh et al., 2002; Morgan, 2009), with a LD_{50} that is more than 5000 mg/kg in rats (Raizada et al., 2001). The Environmental Protection Agency (EPA) classifies azadirachtin in toxicity class IV. The residual effects usually last approximately 4-8 days, depending on the environmental conditions and the plant species treated (Schmutterer, 1998). Azadirachtin is not persistent in the environment due to fast biodegradation in the sunlight (Boursier et al., 2011), therefore they are highly suitable for use in integrated pest management programs (Schmutterer, 1990) and also in organic farming. Today more than 100 commercial neem formulations are used worldwide (Khater, 2012).

Rotenone

Rotenone is a natural plant toxin, isoflavonoid, which occurs naturally in more than 65 plant species. However, most of the commercial supplies are isolated from the roots and rhizomes of the tropical species of the Fabaceae family: cubé or barbasco (*Lonchocarpus utilis* A. C. Sm.) and derris (*Derris elliptica* / Wall./ Benth) (Weinzierl, 2000). Dried *Derris* roots contain approximately 5% of rotenone (Ling, 2003). It has been used for centuries by native tribes of Southeast Asia and South America as fish poison to catch fish and to obtain food. Rotenone has been used as a selective fish poison for managing freshwater fisheries since the 1930s (Whitehead and Bowers, 1983; Ray, 1991; Ling, 2003) to achieve the desired balance of the species. It is considered to be one of the most environmentally benign toxins available for fisheries management. As a commercial insecticide it has been used for more than 150 years and it acts as a metabolic inhibitor, as well as a neurotoxic poison. It inhibits the electron transport chain in the mitochondria that results in failure of the respiratory functions (Ware and Whitacre, 2004). Shortly following exposure to rotenone, the insects quickly stop feeding and death occurs between a few hours and several days later. It is a contact and stomach poison effective on a wide range of insect species including caterpillars, aphids, suckers, trips and other pests found in fruits and vegetables (Tomlin, 2000), including the Colorado potato beetle (*Leptinotarsa decemlineata* Say.), Plum curculio (*Conotrachelus nenuphar* Herbst), *Diabrotica* and *Acalymma* species (Weinzierl, 1998). In the investigation by Wheeler at al. (2001), rotenone reduced the amount of food absorbed by three polyphagous Noctuidae moth species and also their ability to transform the absorbed food to biomass. Its effectiveness in controlling the ectoparasitic mite (*Varroa jacobsoni* Oudemans) of honey bees has been determined by Martel and Zeggane (2002). Rotenone is toxic to cold-blooded animals, less toxic to warm-blooded animals and moderately toxic to humans. Pure rotenone is acutely toxic to mammals (rat oral LD_{50} is 132 mg/kg) but in available formulations, it is much less toxic (Isman, 2006). Rotenone is classified by the EPA in either class I or III (highly toxic or slightly toxic) depending on the product formulation. Rotenone is non-persistent in the environment, quickly broken down in light, air, heat (temperatures must not exceed 25°C) and alkaline conditions. Therefore, it is environmentally friendly (Ray, 1991; Holm et al., 2003). In Europe, the formulations containing rotenone are used as protection agents in organic agriculture. However, in some European countries, such as Austria, Italy, Spain, and Switzerland, its use is partially restricted (Cavoski at al., 2011). Most commercial products come from Central and South America. Rotenone's safety is somewhat controversial, because investigations have shown a connection between the use of rotenone and Parkinson's disease. Acute exposure in rats caused brain lesions, consistent with those observed in humans and animals with Parkinson's disease (Betarbet et al., 2000).

Quassia

Bitterwood tree or quassia (*Quassia amara* L.) is a tropical forest shrub, rarely a small tree, and a member of the Simaroubaceae family. Quassia is indigenous to Northern Brazil and the Guyana and it also grows in Venezuela, Columbia, Argentina, Panama and Mexico. In Guyana, Surin and Brazil insecticidal sprays are traditionally prepared by boiling pieces of quassia wood in water. It was one of the insecticides widely and effectively used before the development of synthetic insecticides (Mancebo et al., 2000). The wood of this plant species, depending on the age, contains 0.14–0.28% of quassinoids (mainly quassin and neoquassin) that exhibit insecticidal activity (Polonsky, 1973; Villalobos et al., 1999). It is a stomach and contact poison and it is one of the few botanicals that have demonstrated systemic properties (Pluke et al., 1999).

A study conducted in India reported the efficacy of quassia extracts on different insects, including mosquitoes, and the results have shown a high oral toxicity (Evans and Raj, 1988). It was found to be effective in controlling aphids, caterpillars, Colorado potato beetles and sawflies. Nematocidal activity has also been reported, as well as selectivity towards beneficial insects such as ladybirds and honeybees (Pluke et al., 1999). Mancebo et al. (2000) conducted a study to determine the antifeedant activity of the quassia extract on Mahagony shootborers (*Hypsipyla grandella* Zeller, *H. robusta* Shankland, Bissen and Weisblat), an important forest pest which attacks wood plants of the Meliaceae family. The extracts showed clear antifeedant activity against *H. grandella* larvae. Soto et al. (2011) also demonstrated that principles from quassia derivatives may play an important role in dealing with *H. grandella* if they are complemented with other integrated pest management preventative tactics. The effects of quassin and neoquassin on the Apple sawfly (*Hoplocampa testudinea* Klug) using spray treatment with the quassia extract were studied by Psota et al. (2010). The extract from the wood reduced the Apple sawfly infestation of fruitlets.

Sabadilla

Sabadilla is extracted from the seeds of the sabadilla lily (*Schoenocaulon officinale* Schltdl. & Cham.), a tropical plant which grows in Central and South America. Native American Indians have used sabadilla against different pests for centuries. In a form of insecticidal dusts obtained by grounding the seeds it was also used by Spanish explorers and colonists (Weinzierl, 2000). The alkaloids produced in sabadila are collectively known as veratrine. Cevadine and veratridine are the most active veratrines and exist in a 2:1 ratio (Dayan et al., 2009). Ripe and aged sabadilla seeds contain approximately 0.3% of alkaloids (Ujvary et al., 1991). Veratrin is also produced by several other species including European white hellebore (*Veratrum album* L.). Sabadilla affects the membrane of nerve cells, causing a loss of nerve function, paralysis and death. It is effective by either contact or ingestion against caterpillars, leaf hoppers, thrips, stink bugs and squash bugs. It is highly toxic to honeybees (Weinzierl, 2000), degrades rapidly when exposed to air and sunlight and has little residual toxicity. Sabadilla is considered among the least toxic of botanical insecticides with an oral LD_{50} of 4000-5000 mg/kg (Dayan et al., 2009). Purified veratrine alkaloids are extremely toxic to mammals (rat oral LD_{50} 13 mg/kg) (Isman, 1996).

Ryania

R*yania speciosa* Vahl. (Flacourtiaceae) is a plant species indigenous to South America. Woody stems of this plant contain alkaloids with insecticidal activity, collectively known as ryanoids. The most active ryanoid is ryanodine and 9,21-dehydroryanodine (Jeffries et al., 1992). The ground stem wood contains less than 1% of ryanoide (Khater, 2012). It interferes with calcium release in muscle tissue, thereby blocking neuromuscular junctions. It is effective by either contact or ingestion against Corn earworm (*Helicoverpa zea* Boddie), European corn borer (*Ostrinia nubilalis* Hübner), and citrus thrips (Regnault-Roger, 2012), Codling moth (*Cydia pomonella* L.), caterpillars, and leaf eating beetles. It is a slow-acting stomach poison and insects stop feeding soon after ingestion. Ryania has a relatively low toxicity to mammals (Dayan et al., 2009). Purified ryanodine is approximately 700 times more toxic than the crude ground or powdered wood. It has a longer residual activity than most other botanical insecticide.

Essential oils and other sources of insecticidal activity

Essential oils are secondary plant metabolites as mixtures of volatile organic compounds. Many of the essential oils (mainly from the Lamiaceae, Myrtaceae, Asteraceae, Rutaceae, Apiaceae, and Laureaceae families) have great insecticidal potential (Khater, 2012). They also possess antiviral, antibacterial, and antifungal properties. They are easy to extract and generally considered broad-spectrum and environmentally friendly because the array of compounds they contain quickly biodegrade in the soil (Misra et al., 1996). Moreover, they are relatively non-toxic to mammals and fish (Koul et al., 2008). Essential oils from different plant species exhibit ovicidal, larvicidal, antifeedant, insecticidal and repellent action against various insect species (Isman, 2000; Cetin and Yanikoglu, 2006). They interfere with insect growth and development by altering feeding behavior and behavior during oviposition and mating. Recent studies have shown that some chemical compounds have neurotoxic modes of action, interfering with the neuromodulator octopamine (Koul et al., 2008). The use of essential oils (basil, citrus peel, eucalyptus, various mint species, lavender and rosemary) in the protection of stored products is well known and many of the essential oils have been recognized as important natural agents in plant protection.

Citrus oils are extracts from citrus peels of different plant species of the Meliaceae and Rutaceae family. Limonene and linalool are two major constituents of some citrus oils and they act as nerve toxins and contact poisons (Weinzierl, 2000). They evaporate quickly after application, leaving no harmful residuals. Limonene is toxic to all the life stages of the fly; eggs, larvae, pupae and adults. It is often applied with pyperonil butoxid to enhance its effectiveness. Limonene extracted from sour oranges (*Citrus* x *aurantium* L.) is toxic to adult Bean weevils (*Callosobruchus phasecoli* Gyll.) (Jacobson, 1982). In a study of Raina et al. (2007), orange oil extract (cca 92% limonene) was efficient against the Formosan subterranean termite (*Coptotermes formosanus* Shiraki), a major urban pest in USA. Linalool is toxic to the eggs and larvae of Caribbean fruit flies (*Anastrepha suspense* Loew) which is supported by the fact that females do not lay eggs in immature grapefruits due to high concentrations of linalool (Khater, 2012). Re et al. (2000) noted that linalool affects ion transport and the release of acetylcholine esterase in insects. In the USA, various plant oils (clove, peppermint, *etc.*) are used by professional pest control operators for cockroach control and against ants and termites (Isman et al., 2011).

Volatile oils from the *Mentha* species have shown to be effective against common stored grain pest; Cowpea weevel (*Callosobruchus maculates* Fabricius) and Red flower beetle (*Tribolium castanum* Herbst) (Tripathi et al, 2000). Citronella (*Cymbopogon nardus* /L. / Rendle) essential oils have been used for over fifty years as an insect repellent. Today they are mostly sold in a form of candles as mosquito repellent (Weinzierl, 2000). Larvicidal activity has also been observed and attributed to the major constituent citronellal (Zaridah et al., 2003). Eucalyptus essential oil can act as an insect repellent and insecticide. Kumar et al. (2012) determined considerable activity of Tasmanian blue gum (*Eucalyptus globulus* /Labill./) oil against the larvae and pupae of the housefly (*Musca domestica* L.), thereby demonstrating its potential for the development of an eco-friendly product for housefly control. Mossi et al. (2011) demonstrated the effective insecticidal and repellent activity of essential oils of seven *Eucalyptus* species (*Eucalyptus dunnii, E. saligna, E. benthamii, E. globulus and E. viminalis*) in the control of the Maize weevil *(Sitophilus zeamais* Motschulsky).

The chemical constituents of essential oils from savory (*Satureja thymbra* L.), oregano (*Origanum onites* L.) and myrtle (*Myrtus communis* L.) were tested for their insecticidal activity against the adult stages of the stored product pests Mediterranean flour moth (*Ephestia kuehniella* Zeller), Indian meal moth (*Plodia interpunctella* Hübner) and the Bean weevil (*Acanthoscelides obtectus* Say). The myrtle oil was more effective than the other oils tested against *A. obtectus* adults. The essential oils of oregano and savory were highly effective against *P. interpunctella and E. kuehniella* (Ayvaz et al., 2010). Ouden et al. (1993) reported a decrease in adult and larval survival of the Cabbage root flies (*Phorbia brassicae* Bch.) when treated with essential oils extracted from the aerial parts of dill (*Anethum graveolens* L.). Palacios et al. (2009) evaluated the insecticidal activity of 12 essential oils on the house fly (*Musca domestica* L.*)*, and among them, the essential oils from sweet orange *(Citrus sinensis* L.) and sour orange fruit peel (*Citrus* x *aurantium* L.) as well as eucalyptus leaves (*Eucalyptus cinerea* F. v. Muell.) were the most effective and could be good candidates for development as fumigants.

A total of 53 plant essential oils were tested for their insecticidal activities against eggs, nymphs, and adults of the Greenhouse whitefly (*Trialeurodes vaporariorum* Westwood), a major pest of greenhouse vegetables, especially tomatoes, cherry tomatoes, cucumbers, and ornamentals. This insect has developed a resistance to many synthetic insecticides. Essential oils from the bay (*Laurus nobilis* L.), caraway seed (*Carum carvi* L.), clove leaf (*Syzygium aromaticum* /L./ Merrill & Perry), lemon eucalyptus (*Corymbia citriodora* /Hook./ K.D. Hill & L. A. S. Johnson), lime (*Citrus × aurantifolia* /Christm./ Swingle), pennyroyal (*Mentha pulegium* L.), peppermint (*Mentha* x *piperita* L.), rosewood (*Aniba rosaeodora* Ducke), spearmint (*Mentha spicata* L.) and tea tree (*Melaleuca alternifolia* /Maiden & Betche/ Cheel) were highly effective against adults, nymphs, and eggs of *T. vaporariorum* (Choi et al., 2003). Regnault-Roger et al. (1993) reported that the essential oils from dill (*Anethum greveolens* L.), basil (*Ocimum basilicum* L.), nutmeg (*Myristica fragrans* Houtt.) and cumin (*Cuminum cyminum* L.) have insecticidal activity against the Bean weevil (*Acanthoscelides obtectus* Say).

Essential oils from rosemary (*Rosemarinus officinalis* L.), vetiver (*Vetiveria zizanoides* /L./ Roberty), thyme (*Thymus vulgaris* L.), ceylon cinnamon (*Cinnamomum zeylanicum* Breyn.), lavender (*Lavandula angustifolia* Mill.), tansy (*Tanacetum vulgare* L.), sweet flag (*Acorus calamus* L.*)*, fennel *(Foeniculum vulgare* Mill.), atlas cedar (*Cedrus atlantica* /Endl./ Manetti ex Carrière) (Koul et al., 2008), marjoram (*Origanum majorana* L.), and sage (*Salvia officinalis* L.) (Pavela, 2004) are also known for their pest control properties.

The results of the investigation on leaf extracts of the eggplant (*Solanum melongena* L.), potato (*Lycopersicum esculentum* Mill.), pepper (*Capsicum annuum* L.) and the fruit extract of eggplants (*S. melongena*) suggest the possibility of future exploitation of these materials in controlling the Cluster caterpillar (*Spodoptera litura* Fab.) and the Castor semi-looper (*Achaea janata* L.) (Devanand and Rani, 2011).

Some of the plant species produce insect growth regulatory compounds which negatively affect the maturation of insect species. Basil (*Ocimum basilicum* L.) produces analogues of insect juvenile hormones, juvocimenes (Balandrin et al., 1985), while chamomile (*Matricaria chamomila* L.) produces precocenes that disrupt the production of insect's juvenile hormones, thereby interrupting their growth while moulting. Juvabione, from the wood of the balsam fir (*Abies balsamea* /L./ Mill.), has a similar mode of action (Khater, 2012).

The insect growth regulatory activity of the Yellow oleander (*Thevetia nerifolia* Juss.), a small tree of the Apocynaceae family, against the Cluster caterpillar (*Spodoptera litura* Fab), was found. The chloroform extract of the leaves was found to be the most active in terms of larval mortality (27.5-61.5 %), pupation (28.4-60.2 %) and adult emergence (19.8-52.8 %) (Ray et al., 2012).

Conclusion

Botanical insecticides are one option in insect pest management and crop protection. The advantages of botanical insecticides lie in their lack of persistence and bioaccumulation in the environment, selectivity towards beneficial insects and low toxicity to humans. Conventional plant protection has negative consequences, such as toxicological and ecotoxicologtical problems, disruption of the natural balance and the promotion of the development of resistance in insects. Due to well documented environmental and human health risks associated with the use of synthetic insecticides, their use in the future will be even more regulated. Concern over the negative impact of synthetic pesticides on the environment and human health ensures a continued and growing interest in searching for novel classes of insecticides with alternative modes of action and promoting the usage of those that are already well established.

References

Akhtar M. (2000). Nematicidal potential of the neem tree *Azadirachta indica* (A. Juss). Integrated Pest Management Reviews 5(1): 57-66

Allan C. G., Miller T. A. (1990). Long-acting pyrethrin formulations. In: Pesticides and Alternatives: Innovative Chemical and Biological Approaches to Pest Control (JE Casida, ed), Elsevier Science Publishers, Amsterdam, 357-364

Antonious G. F. (2004). Residues and Half-Lives of Pyrtehrins on Field-Grown Pepper and Tomato. Journal Environmental Science Health B39(4): 491-503

Arthur F. H., Campbell J. F. (2008). Distribution and efficacy of pyrethrin aerosol to control *Tribolium confusum* (Coleoptera: Tenebrionidae) in food storage facilities. J Stored Products Res 44: 58–64

Ayvaz A., Sagdic O., Karaborklu S., Ozturk I. (2010). Insecticidal Activity of the Essential Oils from Different Plants Against Three Stored-Product Insects. J Insect Sci 10(21): 1-13

Balandrin M. F., Klocke J. A., Wutule E. S., Bollinger W. H. (1985). Natural plant chemicals: sources of industrial and medicinal materials. Science 228: 1154-1160

Betarbet R., Sherer T. B., MacKenzie G., Garcia-Osuna M., Panov A. V., Greenamyre J. T. (2000). Chronic systemic pesticide exposure reproduces features of Parkinson's disease. Nat Neurosci 3: 1301-1306

Bhat B. K. (1995). Breeding Methodologies Applicable to Pyrethrum. In: Pyrethrum Flowers: Production, Chemistry, Toxicology and Uses (JE Casida, GB Quistad, eds) Oxford University Press, New York, USA, 67-94

Boursier C. M., Bosco D., Coulibaly A., Negre, M. (2011). Are traditional neem extract preparations as efficient as a commercial formulation of azadirachtin A? Crop Protection 30(3): 318-322

Casida J. E. (1980). Pyrethrum Flowers and Pyrethroid Insecticides. Environmental Health Perspectives 34: 189- 202

Casida J. E., Quistad G. B. (1995). Pyrethrum: a benefit to human welfare. In: Pyrethrum flowers: Production, Chemistry, Toxicology and Uses (JE Casida, GB Quistad, eds), Oxford University Press, New York, USA, 345-350

Cavoski I., Caboni P., Miano T. (2011). Natural Pesticides and Future Perspectives. In: Pesticides in the Modern World - Pesticides Use and Management (M Stoytcheva, ed), InTech, 169-190

Cetin H., Yanikoglu A. (2006). A study of the larvicidal activity of *Origanum* (Labiatae) species from Southwest Turkey. Journal of Vector Ecology 31: 118-122

Choi Won-Il, Lee Eun-Hee, Choi Byeoung-Ryeol, Park Hyung-Man, Ahn Young-Joon (2003). Toxicity of Plant Essential Oils to *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae). J Econ Entomol 96(5): 1479-1484

Cochran D. G. (1995). Insect resistance to pyrethrins and pyrethroids. In: Pyrethrum Flowers: Production, Chemistry, Toxicology and Uses (JE Casida, GB Quistad, eds), Oxford University Press, New York, USA, 234–238

Crombie L. (1995). Chemistry of pyrethrins. In: Pyrethrum Flowers: Production, Chemistry, Toxicology and Uses (JE Casida, GB Quistad, eds), Oxford University Press, New York, USA, 108–122

Crosby D. G. (1995). Environmental fate of pyrethrins. In: Pyrethrum Flowers: Production, Chemistry, Toxicology and Uses (JE Casida, GB Quistad, eds), Oxford University Press, New York, USA, 194-213

Davies T. G. E., Field L. M., Usherwood P. N. R., Williamson M. S. (2007). DDT, pyrethrins, pyrethroids and insect sodium channels. IUBMB Life 59: 151-162

Dayan F. E., Cantrell C. L., Duke S. O. (2009). Natural products in crop protection. Bioorg Med Chem 17(12): 4022-4034

Devanand P., Rani P. U. (2011). Insect growth regulatory activity of the crude and purified fractions from *Solanum melongena* L., *Lycopersicum esculentum* Mill. and *Capsicum annuum* L. Journal of Biopesticides 4 (2): 118-130

Evans D. A, Raj R. K. (1988). Extracts of Indian plants as mosquito larvicides. Indian J Med Res 88(1): 38-41

Gerberg E. J. (1995). Pyrethrum for control of pests of medical and veterinary importance. In: Pyrethrum Flowers: Production, Chemistry, Toxicology and Uses (JE Casida, GB Quistad, eds), Oxford University Press, New York, USA, 302-310

Glynne-Jones A. (2001). Pyrethrum. Pesticide Outlook 12: 195-198

Govindchari T. R. (1992). Chemistry and biological investigation on *Azadirachta indica* (the neem tree). Curr. Sci. 63: 117-122

Grdiša M., Carović-Stanko K., Kolak I., Šatović Z. (2009). Morphological and Biochemical Diversity of Dalmatian Pyrethrum (*Tanacetum cinerariifolium* /Trevir./ Sch. Bip.). Agriculturae Conspectus Scientificus 74 (2): 73-80

Grdiša M., Babić S., Periša M., Carović-Stanko K., Kolak I., Liber Z., Jug-Dujaković M., Šatović Z. (2013). Chemical diversity of the natural populations of Dalmatian pyrethrum (*Tanacetum cinerariifolium* /Trevir. /Sch. Bip.) in Croatia. Chemistry & Biodiversity 10 (3): 460-472

Greenhill M. (2007). Pyrethrum Production: Tasmanian Success Story. Chronica Horticulturae 47 (3): 5-8

Gunasekara A. S. (2004). Environmental Fate of Pyrethrins. Environmental Monitoring Branch, Department of Pesticide Regulation, Sacramento, CA

Head S. W. (1966). A study of the insecticidal constituents in *Chrysanthemum cinerariaefolium* (1) Their development in the flower head. (2) Their distribution in the plant. Pyrethrum Post 8(4): 32-37

Head S. W. (1973). Composition of pyrethrum extract and analysis of pyrethrins. In Pyrethrum; The Natural Insecticide (JE Casida, ed). Academic Press, New York, NY, USA, 25-49

Holm A., Molander P., Lundanes E., Greibrokk T. (2003). Determination of the pesticide Rotenone in river water utilizing large-volume injection packed capillary column switching liquid chromatography with UV and time-of-flight mass spectrometric detection. J Chromatogr A 983: 43-50

Isman M.B. (1996). Some target and non-target effects of neem and other indigenous plants for control of *Dicaldispa Armigera* Oliver. Neem Newsletter 13(2): 9-10

Isman M. B. (1997). Neem and other botanical insecticides: barriers to commercialization. Phytoparasitica 25: 339-344

Isman M. B. (2000). Plant essential oils for pest and disease management. Crop Protection 19: 603-608

Isman M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Annu. Rev. Entomol. 51: 45-66

Isman M. B., Machial C. M. (2006). Pesticides based on plant essential oils: from traditional practice to commercialization. In: Naturally Occurring Bioactive Compounds, Volume 3 (Advances in Phytomedicine) (M Rai, MC Carpinella, eds), Elsevier, Amsterdam, The Netherlands, 29-44

Isman M. B. (2008). Perspective Botanical insecticides: for richer, for poorer. Pest Manag Sci 64: 8-11

Isman M. B., Miresmailli S., Machial C. (2011). Commercial opportunities for pesticides based on plant essential oils in agriculture, industry and consumer products. Phytochem Rev 10: 197-204

Jacobson M. (1982). Plants insects and man: Their inter-relationship. Econ Bot 36: 346-354

Jeffries P.A., Toia R.F., Brannigan B., Pessah J., Casida J.E. (1992). Ryania insecticide: analysis and biological activity of 10 natural ryanoids. J Agric Food Chem 40: 142–146

Jovetić S., de Gooijer C. (1995). The production of pyrethrins by in vitro systems. Crit Rev Biochem Mol Biol 15: 125–138

Kennedy M. K., Hamilton R. L. (1995). Pyrethrum for control of insects in the home. In: Pyrethrum Flowers: Production, Chemistry, Toxicology and Uses (JE Casida, GB Quistad, eds), Oxford University Press, New York, USA, 311-327

Khater H. F. (2012). Prospects of botanical biopesticides in insect pest management. Pharmacologia 3 (12): 641-656

Kiriamiti H. K., Camy S., Gourdon C., Condoret J. S. (2003). Pyrethrin extraction from pyrethrum flowers using carbon dioxide. Journal of Supercritical fluids 26: 193-200

Kolak I., Šatović Z., Rukavina H., Filipaj B. (1999). Dalmatinski buhač (*Tanacetum cinerariifolium* /Trevir./ Sch. Bip.). Sjemenarstvo 16 (5): 425-440

Koul O., Walia S., Dhaliwal G. S. (2008). Essential Oils as Green Pesticides: Potential and Constraints. Biopestic Int 4(1): 63-84

Kumar P., Mishra S., Malik A., Satya S. (2012). Compositional analysis and insecticidal activity of *Eucalyptus globulus* (family: Myrtaceae) essential oil against housefly (*Musca domestica*). Acta Trop 122(2): 212-218

Ling N. (2003). Rotenone a review of its toxicity and use for fisheries management. Science for Conservation 211. Department of Conservation, Wellington, New Zealand, 8

Lowery D. T., Isman M. B. (1995). Toxicity of neem to natural enemies of aphids. Phytoparasitica 23: 297–306

Mancebo F., Hilje L., Mora G. A., Salazar R. (2000). Antifeedant activity of *Quassia amara* (Simaroubaceae) extracts on *Hypsipyla grandella* (Lepidoptera: Pyralidae) larvae. Crop Protection 19: 301-305

Martel A. C., Zeggane S. (2002). Determination of acaricides in honey by high-performance liquid chromatography with photodiode array detection. J Chromag A 954: 173-180

Misra G., Pavlostathis S. G., Perdue E. M., Araujo R. (1996). Aerobic biodegradation of selected monoterpenes. Appl Microbiol Biotechnol 45: 831–838

Mordue A. J., Blackwell A. (1993). Azadirachtin: an update. Journal of Insect Physiology (39) 11: 903-924

Mordue A. J; Simmonds M. S. J., Ley S.V., Blaney W. M., Mordue W., Nasiruddin M., Nisbet A. J. (1993). Actions of azadirachtin, a plant allelochemical, against insects. Pestic Sci 54: 277-284

Morgan E. D. (2009). Azadirachtin, a scientific gold mine. Bioorganic and Medicinal Chemistry 17: 4096-4105

Morris S. E., Davies N. W., Brown P. H., Groom T. (2005). Effect of drying conditions on pyrethrins content. Ind Crop Prod 23 (1): 9-14

Mossi A. J., Astolfi V., Kubiak G., Lerin L., Zanella C., Toniazzo G., de Oliveira D., Treichel H., Devilla I. A., Cansian R., Restello R. (2011). Insecticidal and repellency activity of essential oil of *Eucalyptus* sp. against *Sitophilus zeamais* Motschulsky (Coleoptera, Curculionidae) Journal of the Science of Food and Agriculture. 91 (2): 273–277

Naumann K., Currie R. W., Isman, M. B. (1994). Evaluation of the repellent effects of a neem insecticide on foraging honeybees and other pollinators. *Can Entomol* 126: 225–230

Ouden H. D., Visser J. H., Alkena D. P. W., Dei J. J., Derk P. S. M. (1993). Experiments with volatile substances in slow release formulations causing repellency for oviposition by the cabbage root fly, *Phorbia brassicae* (Diptera : Anthomydae). J. Appl. Entomol. 115: 307-312

Palacios S. M., Bertoni A., Rossi Y. Santander R., Urzúa A. (2009). Efficacy of Essential Oils from Edible Plants as Insecticides Against the House Fly, *Musca Domestica* L. Molecules 14: 1938-1947

Pavela R. (2004). Insecticidal activity of certain medicinal plants. Fitoterapia 17: 745–749

Pavela R. (2009). Effectiveness of Some Botanical Insecticides against *Spodoptera littoralis* Boisduvala (Lepidoptera: Noctudiae), *Myzus persicae* Sulzer (Hemiptera: Aphididae) and *Tetranychus urticae* Koch (Acari: Tetranychidae). Plant Protect Sci 45(4): 161–167

Pluke H. R. W., Permaul D., Leibee G. L. (1999). Integrated Pest Management and the Use of Botanicals in Guyana, Inter Americal Institute for Cooperation on Agriculture, Georgetown, Guyana, South America, 77

Polonsky J. (1973). Quassinoid bitter principles. Fortsch Chem Org Naturst 30: 101-150

Psota V., Ouředníčková J., Falta V. (2010). Control of *Hoplocampa testudinea* using the extract from *Quassia amara* in organic apple growing. Horticultural Science 37 (4): 139-144

Raina A., Bland J., Doolittle M., Lax A., Boopathy R., Folkins M. (2007). Effect of Orange Oil Extract on the Formosan Subterranean Termite (Isoptera: Rhinotermitidae). J Econ Entomol 100(3): 880-885

Raizada R. B., Srivastava M. K., Kaushal P. A., Singh R. P. (2001). Azadirachtin, a neem biopesticide: subchronic toxicity assessment in rats. Food and Chemical Toxicology 39: 477-483

Ray D. E. (1991). Pesticides derived from plants and other organisms. In: Handbook of Pesticide Toxicology (WJ Hayes Jnr., ER Laws Jnr., eds), Academic Press, New York, USA, 599

Ray D. P., Dutta D., Srivastava S., Kumar B., Saha S. (2012). Insect Growth Regulatory Activity of *Thevetia nerifolia* Juss. against *Spodoptera litura* (Fab.). Journal of Applied Botany and Food Quality 85: 212-215

Re L., Barocci S., Sonnino S., Mencarelli A., Vivani C., Paolucci G.,Scarpantonio A., Rinaldi L., Mosca E. (2000). Linalool modifies the ovicidal activity of the essential oil of *Anethum sowa* Kurz against *Callosobruchus maculatus* F. (Coleoptera:Bruchidae). Insect Sci Appl 21: 61-66

Regnault-Roger C., Hamraoui A., Holeman M., Theron E., Pinel R. (1993). Insecticidal effect of essential oils from Mediterranean plants upon Acanthoscelides obtetus (Say) (Coleoptera Bruchidae), a pest of kidney bean (*Phaseolus vulgaris* L.) J Chem Ecol 14: 1965–1975

Regnault-Roger C. (2012). Botanicals in Pest Management. In: Integrated Pest Management: Principles and Practice (DP Abrol, U Shankar, eds), CPI Group (UK) Ltd., Croydon, 123 -124

Rice P. J., Coats J. R. (1994). Insecticidal properties of monoterpenoids derivatives to the housefly (Diptera: Muscidae) and red flour beetle (Coleoptera: Tenebrionidae). Pesticide Science 41: 195-02

Rosenthal G. A., Berenbaum M. R. (1991). Herbivores: Their interaction with secondary plant metabolites, Vol II Ecological and evolutionary processes, 2nd edition Academic press, San Diego

Sadre N. L., Deshpande V. Y., Mendulkar K. N. , Nandal D. H. (1983). Male *Azadirachta indica* in different species. Proc 2nd Int. Neem Conf. Rauischholzhausen, pp 482

Salehzadeh A., Jabbar A., Jennens L., Ley S. V., Annadurai R. S., Adams R., Strang R. H. C. (2002). The effects of phytochemical pesticides on the growth of cultured invertebrate and vertebrate cells. Pest Management Science 58: 268–276

Sawicki R. M., Thain E. M. (1962). Insecticidal activity of Pyrethrum extract and its knock-down activities of the four constituents. J Sci Food Agri 13: 292

Schafer H., Wink M. (2009). Medicinally important secondary metabolites in recombinant microorganisms or plants: progress in alkaloid biosynthesis. Biotechnology Journal 4(12): 1684-1703

Schmutterer H. (1990). Properties and Potential of natural Pesticides from the neem tree, *Azadirachta inidica*. Ann Rev Entomol 35: 271–297

Schmutterer H. (1997). Side effects of neem (*Azadarichta indica*) products on insect pathogens and natural enemies of spider mites and insects. J Appl Entomol 121: 121-128

Schmutterer H. (1998). Potential of azadirachtin-containing pesticides for integrated pest control in developing and industrialized countries. Journal of Insect Physiology 34(7): 713–719

Schmutterer H., Singh R. P. (1995). In: List of Insects Susceptible to Neem Products (H. Schmutterer, ed.), VCH Publication, New York, USA

Scott I. M., Jensen H., Scott J. G., Isman M. B., Arnason J. T., Philogène B. J. R. (2003). Botanical Insecticides for Controlling Agricultural Pests: Piperamides and the Colorado Potato Beetle *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae). Archives of Insect Biochemistry and Physiology 54: 212–225

Sheppard D. C., Swedlund B. (1999). Toxicity of individual pyrethrin esters to house flies (Diptera: Muscidae). J Entomol Sci 35: 279-282

Siddiqui B. S., Rasheed M. Ilyas F., Gulzar T., Tariq R. M., Naqvi S.N. H. (2004). Analysis of insecticidal *Azadirachta indica* A. Juss. Fractions, Velang der Zeitschrift fur Naturforschung 59: 104-112

Silcox C. A., Roth E. S. (1995). Pyrethrum for control of pests of agricultural and storedproducts. In: Pyrethrum flowers: Production, Chemistry, Toxicology, and Uses (JE Casida, GB Quistad, eds). Oxford University Press, New York, 287-301

Sonderlund D. M. (1995). Mode of action of pyrethrins and pyrethroids. In: Pyrethrum flowers: Production, Chemistry, Toxicology, and Uses (JE Casida, GB Quistad, eds), Oxford University Press, New York, USA, 217-233

Soto F., Hilje L., Mora G. A., Carballo M. (2011). Phagodeterrence by *Quassia amara* (Simaroubaceae) wood extract fractions on *Hypsipyla grandella* (Lepidoptera: Pyralidae) larvae. Rev biol Trop 59(1): 487-499

Thacker J. R. M. (2002). An Introduction to Arthropod Pest Control. Cambridge University Press, Cambridge, UK, 26

Todd G. D., Wohlers D., Citra M. (2003). Toxicology Profile for Pyrethrins and

Pyrethroids', Department of Health and Human Services, Agency for Toxic

Substances and Disease Registry, Department of Health and Human Services. Atlanta, GA, U.S

Tomlin C. D. S. (2000). The Pesticide Manual. 12th Ed. British Crop Protection Council. Surrey, England, 178-179

Tripathi A. K., Prajapati V., Aggarwal K. K., Kumar S., Prajapti V., Kumar S., Kukreja A. K., Dwivedi S., Singh, A. K. (2000). Effects of volatile oil constituents of *Mentha* species against stored grain pests, *Callosobrunchus maculatus* and *Tribolium castanum*. J. Med. Arom. Plant Sci. 22: 549–556

Ujváry I., Eya B. K., Grendell R. L., Toia R. F., Casida J. E. (1991). Insecticidal activity of various 3-acyl and other derivatives of veracevine relative to the Veratrum alkaloids veratridine and cevadine. J Agric Food Chem 39: 1875-1881

Villalobos R., Marmillod D., Ocampo R., Mora G., Rojas C. (1999). Variations in the quassin and neoquassin content in *Quassia amara* (Simaroubaceae) in Costa Rica Ecological and Management Implications. Acta Horticulturae 502: 369–375

Ware G. W., Whitacre D. M. (2004). The Pesticide Book. 6th Edn., MeisterPro Information Resources, Ohio, USA, 488

Weinzierl R. (1998). Insect management for commercial vegetable crops. In: 1998 Illinois Agricultural Pest Management Handbook (K Steffey, ed),. University of Illinois at Urbana-Champaign, 181–208

Weinzierl R. A. (2000). Botanical insecticides, Soaps and Oils. In: Biological and Biotechnological Control of Insect Pests (JE Rechcigl, NA Rechcigl, eds), Lewis publishers, Boca Raton, New York, USA, 110-130

Wheeler G. S., Slansky F., Yu S. J. (2001). Food consumption, utilization and detoxification enzyme activity of larvae of three polyphagous noctuid moth species when fed the botanical insecticide rotenone. Entomol Exp Appl 98: 225-239

Whitehead D. L., Bowers W. S. (1983). Natural Products for Innovative Pest Management, Pergamon Press, New York

Winney R. (1979). Performance of pyrethroids as domestic insecticides. Pyrethrum Post 13(4): 132-136

Woodward D. L., Colwell A. E., Anderson N. L. (1985). Use of pyrethrin larvicide to control *Culicoides variipennis* (Diptera: Ceratopogonidae) in an alkaline lake. J Am Mosq Control Assoc 1: 363-368

Wyss E., Daniel C. (2004). Effects of autumn kaolin and pyrethrin treatments on the spring population of *Dysaphis plantaginea* in apple orchards. J Appl Entomol 128 (2): 147-149

Zaridah M. Z., Nor Azah M. A., Abu Said A., Mohd. Faridz Z. P. (2003). Larvicidal properties of citronellal and *Cymbopogon nardus* essential oils from two different localities. Trop Biomed 20: 169–174

Zehnder G., Warthen J. D. (1988). Feeding inhibition and mortality effects of neem-seed extract on the Colorado Potato Beetle (Coleoptera: Chrysomelidae). J Econ Entom 81(4): 1040-1044

Zong-Mao C., Yun-Hao W. (1996). Chromatographic methods for the determination of pyrethrin and pyrethroid pesticide residues in crops, foods and environmental samples. J Chromatogr A 754: 367

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